

*Tools for Cleaning Up Illinois Diesel:  
Technology, Funding & Collaboration*

# *Hydraulic Hybrids*

---

*Cost-Effective  
Clean Urban Vehicles*



**Matthew Brusstar**

*Senior Technical Advisor*

*Office of Transportation and Air Quality*

*U.S. Environmental Protection Agency*

*May 2, 2006*

***Clean Automotive Technology***

*[www.epa.gov/otaq/technology](http://www.epa.gov/otaq/technology)*

# What is a Hybrid?

---

- **A hybrid drivetrain is simply another kind of transmission**
  - Manual, automatic or hybrid
  - It is one that can recover, store and reuse power either electrically or hydraulically.
- ***A hybrid vehicle, in addition to its main engine, has a drive train that contains:***
  - An energy storage system
  - A special drive system to convert the stored energy to motive power

## **Hydraulic Hybrids**

- Store energy in hydraulic accumulators
- Use hydraulic pump-motors

## **Electric Hybrids**

- Store energy in batteries and/or ultra-capacitors
- Use electric generator-motors

# Why Hydraulic Hybrids?

---

- ❑ Highest possible fuel economy
- ❑ Lowest incremental cost
  - Shortest payback to owner
  - Highest lifetime-savings
- ❑ Ultra-low emissions
- ❑ Enables unique high efficiency engines
- ❑ Greater reductions in greenhouse gases
- ❑ Greater reductions in imported oil

*Vehicle technologies that deliver  
real-world results cost-effectively!*

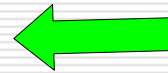
# Ways to Increase Vehicle Fuel Economy...

---

## 1. Capture and re-use energy lost to friction braking

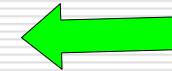
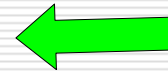
- ✓ Regenerative Braking

Cost-Effective  
Hybrids



## 2. Improve average efficiency of the engine / drivetrain

- ✓ Shutoff engine at idle
- ✓ Operate engine at "sweet" spot
- ✓ Shutoff engine at all times when not needed



## 3. *Reduce the energy needs at the wheels*

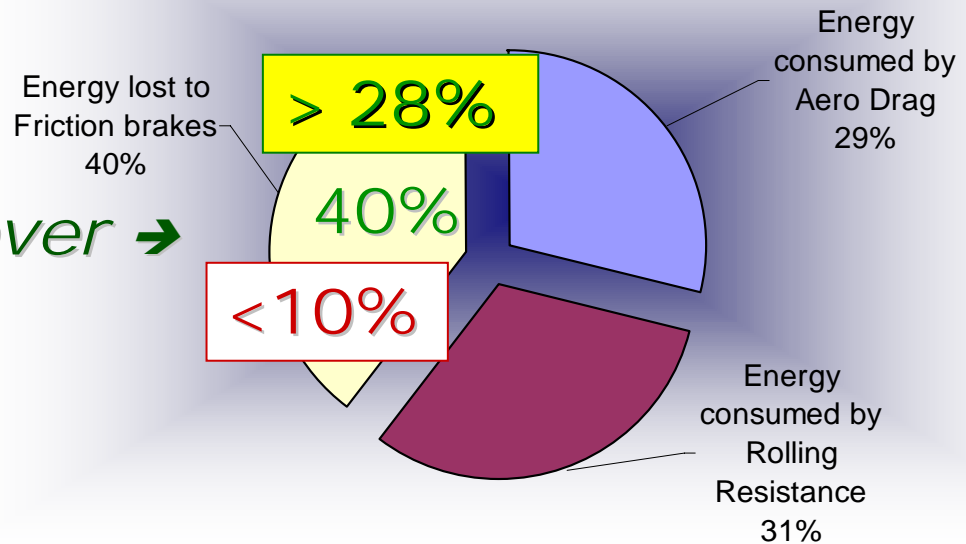
- ✓ Reduce Aerodynamic Drag
- ✓ Reduce Rolling Resistance

# Regenerative Braking

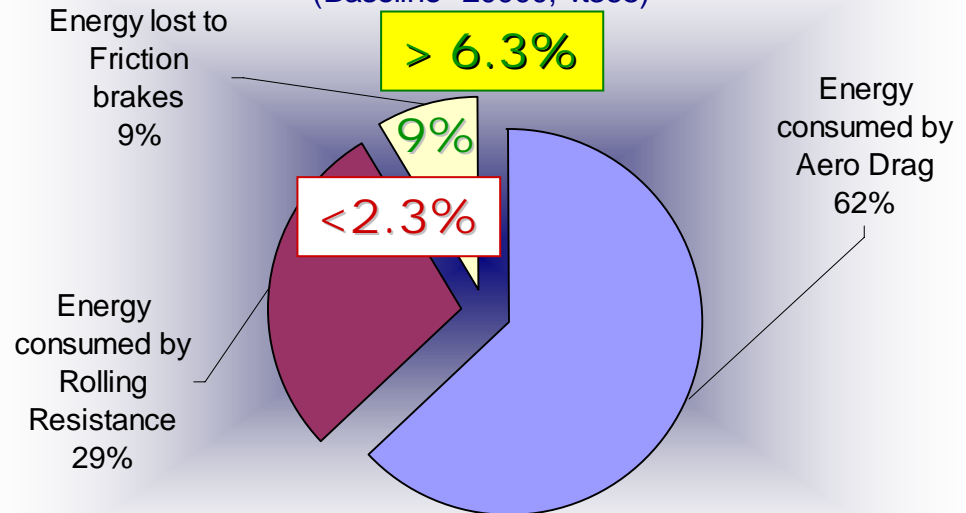
*Hybrids try to recover → this energy*

## Where Does the Energy at the Wheels Go?

EPA City Cycle Energy Delivered to the Wheels  
(Baseline- 20000 lbs, vt365)



EPA Highway Cycle Energy Delivered to the Wheels  
(Baseline- 20000, vt365)



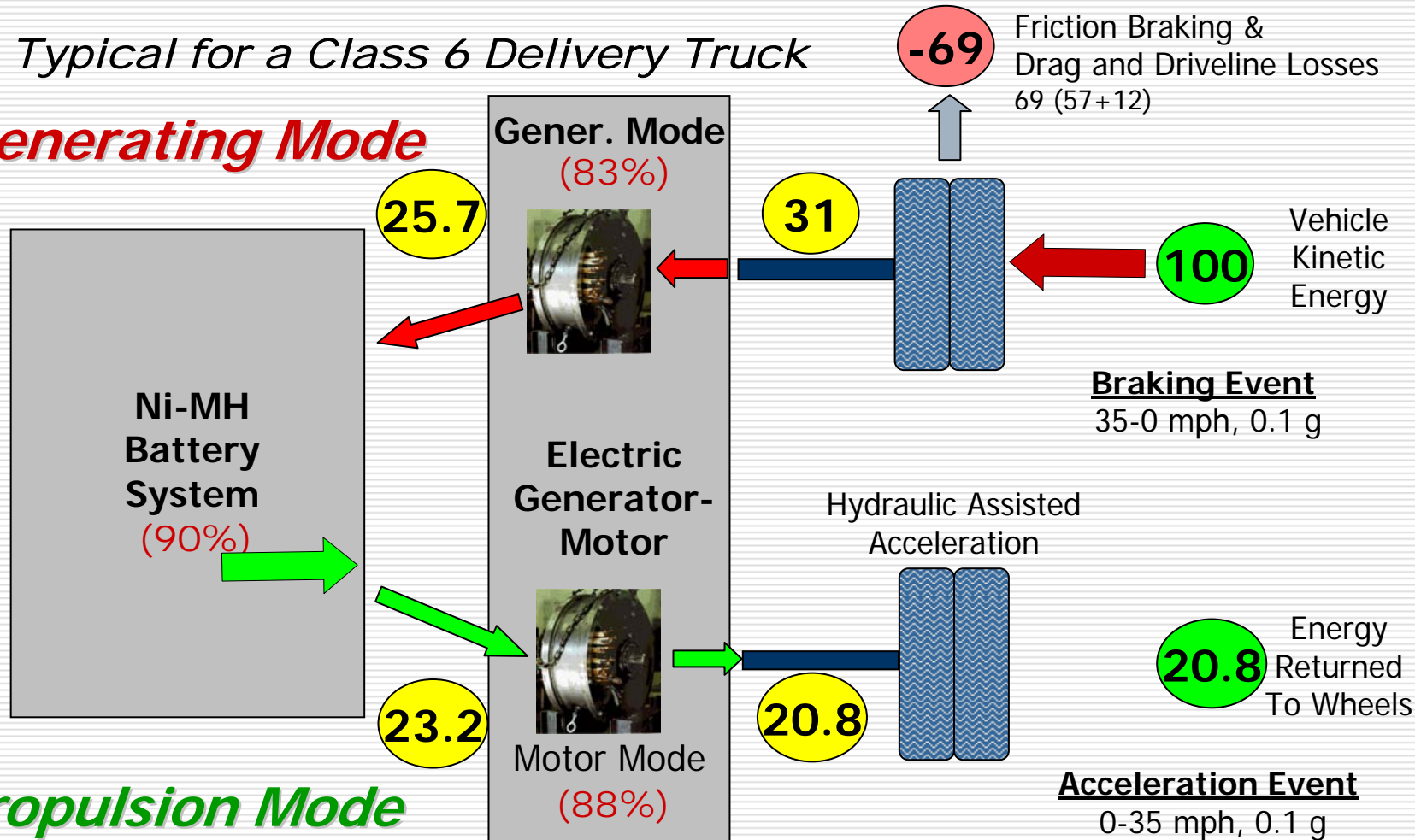
Electric Hybrids <25%

Hydraulic Hybrids >70%

# Efficiencies While Braking/Accelerating Electrically

*Data Typical for a Class 6 Delivery Truck*

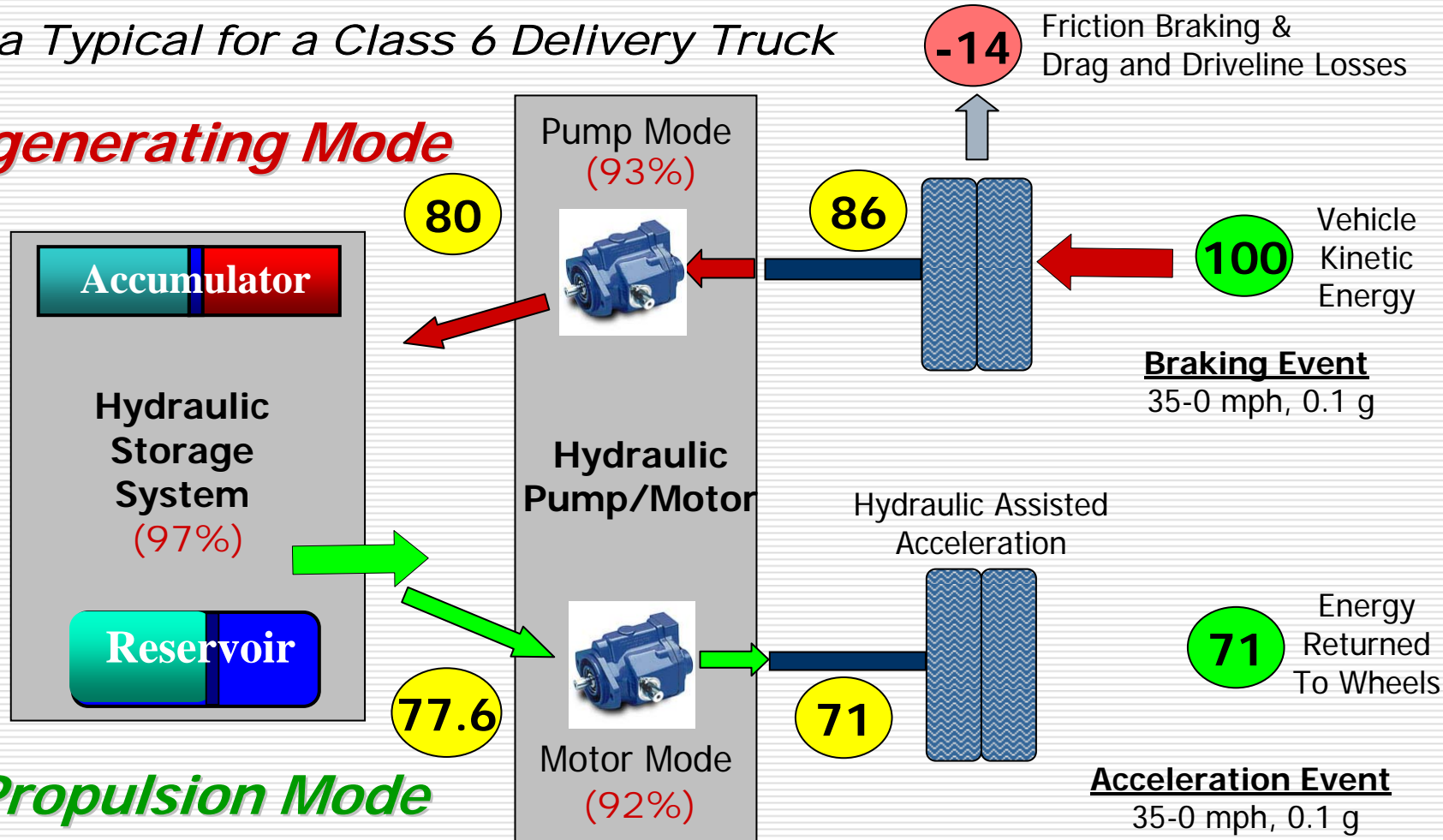
***Regenerating Mode***



# Efficiencies While Braking/Accelerating Hydraulically

*Data Typical for a Class 6 Delivery Truck*

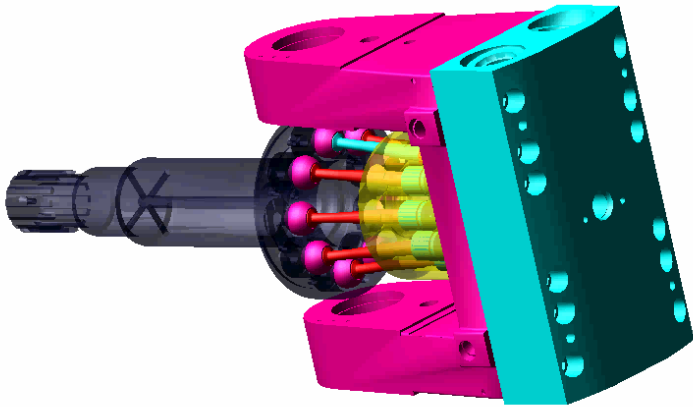
## *Regenerating Mode*



# Hydraulic Components

## Integrated Bent-Axis Hydraulic Pump-Motors

Last\_Run Time= 0.0003 Frame=3



1. **Specific Power:** ~ 7 kw/kg
2. **Specific Cost:** \$9/kg

## Hydraulic Hybrid Accumulators



1. **Charge/discharge cycle efficiency:** 95-99%
2. **Specific power:** High pressure accumulator (with oil that transfers the power/energy) can deliver very high specific power in excess of 5 kw/kg
3. **Energy density:** >50 kw-sec/gal
4. **Specific energy:** ~8 kw-sec/kg
5. **Specific costs:** \$10/kg



# Parallel Hydraulic Hybrid Operation

---

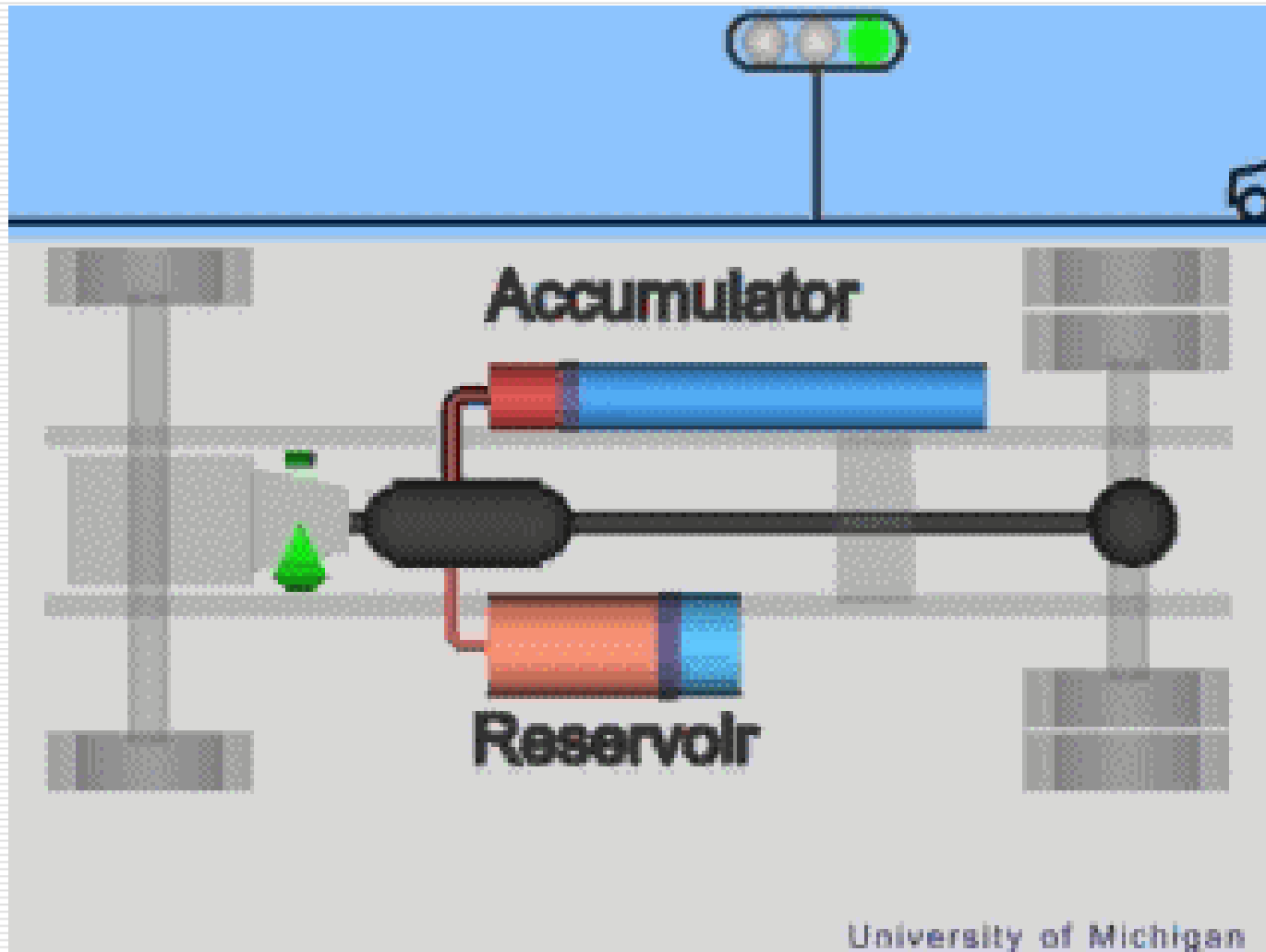


Illustration courtesy of **Automotive Research Center** – University of Michigan

# Series Hydraulic Hybrid Operation

---

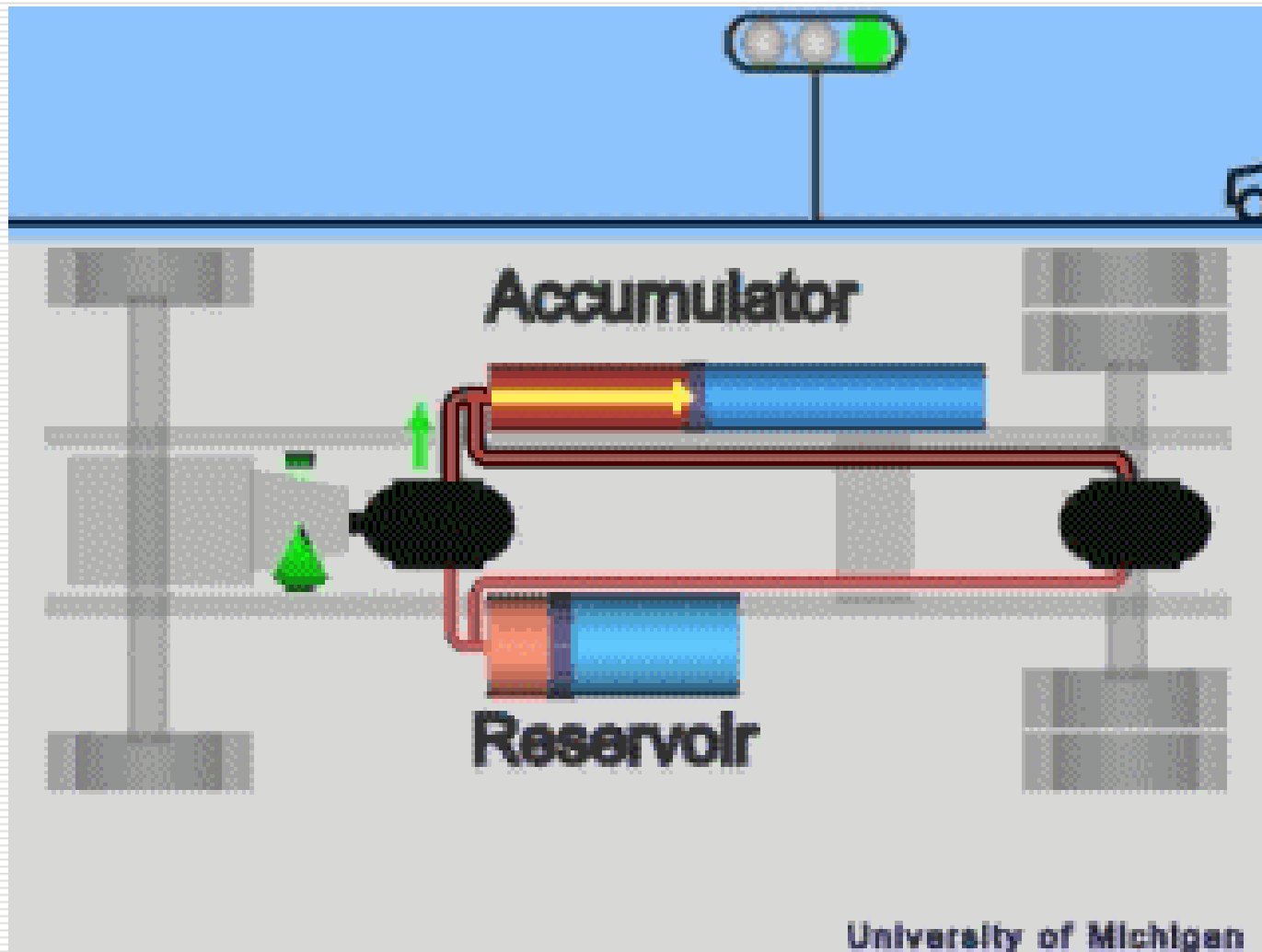


Illustration courtesy of **Automotive Research Center** – University of Michigan

# Hydraulic Hybrids Efficiency

## Parallel versus Series

---

Series hybrid designs enable the next step in hybrid design – big opportunities for:

- More efficient engine operation, and
- Unique, even more cost-effective engines
- Higher fuel economy with less incremental cost

Hybrid Configurations	Vehicle Fuel Economy Improvement
<b>Mild</b> Hybrid (parallel, launch assist with conventional engines)	20-40%
<b>Full</b> Hybrid (series) with conventional engines	60-80%
<b>Future Full</b> Hybrid (series) with advanced engines, improved aerodynamics, and tires	100-120%

# This is Just the Beginning... More FE Improvements Coming!

---

## ***Advanced High Efficiency Engines Enabled by Full Series Hybrids***

### ***HCCI - Homogenous Charge Compression Ignition***

- Diesel efficiency levels from gasoline (Tier2 Bin 2)

### ***Alcohol-Fuel Engines***

- Cost-effective, high efficiency (Tier2 Bin 2 potential)

### ***Thermal Energy Recovery (alcohol fuel)***

- Recover energy from the waste exhaust heat

### ***Complete Variable Displacement Engine***

- Twin Crank engine to maximize engine efficiency yet have peak power available on-demand

### ***Free Piston Engine***

- Hydraulic power directly from engine – no crank

# Types of Questions You Need to Ask Yourself To “Spec-out” Fleet Hybrids

---

- ☐ What level of emission reduction do you want?
  - Dock/garage air quality: no idle, “silent getaway”
  - On the road: cycle emissions
- ☐ How long can you wait for the system to pay for itself?
  - What fuel economy gain do you desire? (mpg)
  - How much can you save on brake maintenance?
- ☐ Does your fleet have a duty-cycle that will bring suitable fuel economy gains?
- ☐ How much weight gain can you tolerate?
- ☐ What level of redundancy do you need (limp home)?
- ☐ Do you need on-board electricity?

# Types of Questions to Ask Hybrid Manufacturers

---

- ☐ What is your “round-trip” wheel-to-wheel regeneration efficiency?
- ☐ Do you shut engine off at idle?
- ☐ Over what drive cycle was the vehicle tested?
- ☐ What is engine efficiency over entire drive cycle?
- ☐ What percent is the engine off over drive cycle?

# Challenges to Proliferation of Hybrids in Commercial Vehicles

---

	Assessment of Today's Systems	Expected from Full Series System
1. Fuel Economy Increase	15-40%	60+ %
2. Incremental Cost	?	10-15% of base vehicle (high volumes)
3. Payback Period	?	2-3 years

***EPA is focusing its efforts on full series "hydraulic" hybrid designs***

# Growing Interest In Using Hydraulic Hybrids

---

## ■ Interested Groups

- ✓ **Users/Fleets**– Army, refuse industry, Hybrid Truck User's Forum's (HTUF) Hybrid Parcel Delivery WG is now pursuing hydraulic hybrids
- ✓ **Manufacturer/Suppliers** – International, Eaton, Parker-Hannafin, Dana/Permodrive, HybraDrive, Hydraulic Innovations
- ✓ **Hydraulic Hybrid Working Group** – formed through NextEnergy; focusing on industry issues associated with commercializing hydraulic hybrids - [www.nextenergy.org/industrygroups](http://www.nextenergy.org/industrygroups)

## ■ Publications

- ✓ **2004 EPA Technical Report** – focus on the efficiency, cost and payback of hydraulic hybrid technology  
[www.epa.gov/otaq/technology/#tech](http://www.epa.gov/otaq/technology/#tech)
- ✓ **2005 SAE Paper** - Hydraulic versus Electric Hybrid Fuel Economy – *Ricardo paper (SAE# 2005-01-1164)*



# *EPA's Full Series Hydraulic Hybrid SUV Demonstration Vehicle*

---

## **Communicates a Vision of "Production Potential" for SUV's and Light Trucks**

- Diesel & 4-WD hydraulic hybrid ("HH") shows 85% fuel economy improvement (130% in city) & better acceleration
- \$2200 incremental cost add for diesel engine and hydraulic hybrid technology means excellent 1-2 year payback for consumer (assumes high volume)



# *EPA's Full Series Hydraulic Hybrid Urban Delivery Vehicle*

## **Hydraulic Hybrid UPS Package Car Demo Creates Visibility With "Real World" Experience**



- 60-70% mpg improvement in city driving
- 2-3 year payback has attracts attention from fleets
- Potential for net Lifetime savings over \$20,000
- Demonstration to accelerate technology transfer to industry & familiarity with technology
- Partners (UPS, Eaton, International Truck, U.S. Army)

New York Times (Feb 10, 2005) – “ **The Environmental Protection Agency and the United Parcel Service announce a test project today demonstrating a new type of transmission that could save energy and reduce pollution.**”